GIANT SUNS[1]

By Professor H. H. TURNER

SAVILIAN PROFESSOR OF ASTRONOMY, OXFORD UNIVERSITY

THE new secrets wrested from the stars have chiefly come, not from the increase in size of telescopes, but from the new appliances attached to them, such as the photographic plate, the spectroscope, and by this time many others. The lines in the spectra of stars tell us what the stars are made of, how they may be classified accordingly, how fast they are moving, how bright they really are (this is an amazing recent discovery), and by inference how far away, and may yet have other surprises in store. For the moment we are chiefly concerned with the classification. The Harvard system gives us a number of classes denoted by the capital letters O B A F G K M R N. The fact that the order is not quite the same as that of the alphabet represents a revision of early ideas, chiefly due to the gradual accumulation of intermediate types, which make a nearly continuous series.

Now a series of stars in order is probably a representation of growth; just as the growth of trees may be illustrated by selecting various stages from the same wood, an illustration originally given by Sir W. Herschel. But we have seen a tree grow, and we know independently that it grows up from the acorn through the sapling to the giant oak; while we have not had time to see a star grow and were thus in ignorance whether the changes are from B towards M or from M towards B, though by this time we have an immense number classified. The classification has been largely the work of an American lady, Miss Cannon. I am told that there is a man who can deftly straighten rifle barrels—he gives a glance along the barrel, a tap with a hammer, and lo! it is straight. His value is recognized at some £15 a week. Miss Cannon has the same deftness with spectra—but I fear that (to judge from the report of the Board of Visitors of Harvard Observatory) her great skill is not so appropriately rewarded.

Now it is obviously important to find out, if we can, which is the direction of a star's growth, and we seemed to have an im-

[1] From an address before the Royal Institution of Great Britain.

portant clue when the spectral classification was connected with the temperature of a star, or rather its *surface* temperature, which is all we can get at. The outside is the coolest, just as the edges of a plate of porridge are the coolest, as most of us have learned by early and rather painful experience. And yet the outside of a star is hot enough. The temperature is again estimated from the spectrum, though this time not from the lines but from the relative intensities of the ends, and the O B A end is undoubtedly hotter than the other. We may give as illustrations 15,000° for B, 5,000° for G, and 2,500° for M. Does this settle the matter? We know that there is a general tendency for all bodies to cool which points to the direction C B—M N as the order of events; but it was also known that under the stress of gravitation a star might rise in temperature, in which case the growth might be the other way. Still the former alternative commended itself more generally; and when Professor W. W. Campbell found that the velocities of stars (also determined with the spectroscope) were smaller for type B than the type M, the facts were interpreted to mean that a star moved more quickly with advancing age (because M stars were older than B). The idea that the life of a star was spent in passage down the series O B—M was indeed pretty firmly established at the time when the revolution came.

The revolution began with the advent of a young American research student, Mr. H. N. Russell, to Cambridge in 1904–6. It is to the credit of Mr. A. R. Hinks that he made so much of this brilliant young student, setting him on the way to determine the distances of a number of stars by photography with the instruments which he (Mr. Hinks) has spent much time and labor in perfecting. This was the first element in his success. The next was that on his return to America he got from the Harvard Observatory—that storehouse of astronomical facts—the spectral types of his stars; and combining these with the measures of distance (which told him the intrinsic brightness or luminosities of the stars) he found that stars of the same spectral type M fell into two distinct groups separated by an interval. There were very bright stars, now called Giants, and there were very faint ones, now called Dwarfs, but none of intermediate stature.

The same was true in minor degree for stars of other types, but as the B end of the series was approached the gap gradually disappeared much in the way that the gap between the legs of a stepladder gradually lessens as we approach the top. Indeed Russell's diagram of his results is very like a stepladder, the top representing the B stars followed by A, F, G, K, M, in

descending order, and the gap between the two legs of the ladder representing the difference in luminosity, as the intrinsic brightness of a star has come to be called. Russell brought this diagram with him when he came to attend the meeting of the Solar Union at Bonn in 1913. It is sad to remember the occasion, for the most friendly relations seemed to have been permanently established between the various nations assembled. We remember with especial regret the trip on a great steamer on the Rhine which ended the meeting, and, alas! was the end also of our hopes of a permanent friendliness, for before the year had passed the Great War had shattered them all. It was on his return from Germany through England that Russell showed us his stepladder diagram at the Royal Astronomical Society, and expounded his views on the evolution of a star, which were that its life began at the foot of the upright leg, the ascent of which signified that the star was growing continually hotter and changing its spectral type meantime from M upwards towards B, that at B the increase of temperature was arrested and after a time cooling began carrying the star down the inclined leg of the ladder through changes in the reverse order. The only weak spot in the evidence arose from the small number of observations. To determine the actual or intrinsic brightness of a star we must know its distance, and there are not many stars of which the distance can be easily measured, and though Russell had himself increased the number, the total was still not large. To get further evidence he had recourse to indirect estimates of distance, especially those of clusters of stars. We have lately become more and more aware of the association of stars in clusters represented by their common movement, somewhat in the way that the movements of a flock of birds migrating from one place to another are associated. If we may accept this evidence, and if we can determine the distance of any one star in the cluster, the distances of the others can be inferred. In Russell's skilful hands this evidence was collated and found to strengthen his conclusions.

Let us pause here for a moment to reflect on the inherent probability of the suggestion. Is it not after all much more likely that a star first rises in temperature and then falls rather than that it should be permanently either rising and falling? Now that the idea has been put forward, and that there seems to be not only good evidence of this change in the sky, but, as we shall presently see, also good theoretical reason for it, we wonder why the idea was not the most natural one to adopt from the first. But curiously enough it was not the one adopted by astronomers, with the notable exception of Sir Norman Lock-

yer, who made the same suggestion as Russell's (though on different grounds) many years before. May I give a crude illustration from our ordinary life of the mistake that was made by many of us? It is as though we had taken the amount of hair as an indication of the age of a man. In very early life the amount of hair is small, it increases with age up to a certain point, but then it begins to decrease until a very old man often has as little hair as a newborn baby. We could give Shakespeare's Seven Ages of Man according to the amount of hair in the same diagrammatic form as Russell's stepladder, beginning with the baby at the foot of the upright leg, ascending to the man in middle life with maximum hair (corresponding to the maximum temperature), and placing the greater ages down the inclined leg till we arrive again at a bald pate. Shakespeare reminds us with his phrase about the voice "turning again toward a childish treble" that not only the hair but the voice goes through changes which show a reversal after middle life. We were practically confusing the baby stars with the old man stars until Russell called our attention to the fact; and now it seems quite easy to make the distinction. But there was some hesitation before the new views were accepted at all, chiefly on account of the lack of sufficient measures of distance, which left room for doubt. Recently the evidence has been reinforced in a remarkable way by a totally new and unexpected method for inferring the distances of stars, due to Mr. W. S. Adams, of the Mount Wilson Observatory in California. His discovery is that if we have two stars, one of which is very bright intrinsically and the other faint, but both of the same spectral type, we can find two lines of the spectra which have different relative intensities: let us call them A and B. In the bright star A is more intense than B, in the faint star B will be more intense than A. Now observe that this difference will persist however far we may remove the stars from us. By altering the distances we may make the brighter star *appear* the fainter, but we can pierce its disguise by noting simply that the line A in the spectra is the more intense, so that if the star *appears* faint we see at once that this must be due to its greater distance. In fact we can infer the distance from the relative intensities of the lines A and B, so that Adams has really given us a new method of inferring distances. The new method has the further advantage of requiring far less labor than the old method of parallax; in fact, when once the spectrum has been photographed the further labor required is quite small, so that by this time Adams has been able to give us the luminosity of hundreds of new stars, and by this overwhelming evidence confirms Russell's results derived from merely a few.

In addition to this confirmation by new observations we have had an independent confirmation by the brilliant theoretical work of Professor Eddington, who has attacked the problem of the life of a star mathematically. He supposed a mass of gas first of all to be simply under the action of its own gravity. It will consequently contract, and owing to the contraction will rise in temperature; but Professor Eddington soon found that this simple hypothesis would not answer—it led him to impossible results. Clearly something else beside gravity must be at work, and he was driven to the further hypothesis that the *radiation-pressure* inside the star played an important part in its history. Radiation-pressure (or if we like to call it so, light-pressure) is what makes the tail of a comet. As a comet approaches the sun it begins to feel the effects of the fierce light, which is known to be able to drive away very small particles from the head of the comet, much as we can blow away chaff from wheat. In consequence of this action the small dust-like particles which may exist in the head are believed to be driven outwards to form the tail. But this force is not merely in existence on the outside of the sun, it permeates its whole body. A particle inside the sun is of course receiving radiation-pressure from all its surroundings, but the pressure will naturally be greater on the hotter side, *i. e.*, on the side of the sun's center. Working out the problem afresh with the addition of this new factor, Professor Eddington has obtained results which agree satisfactorily with the observed effects, and indeed the closeness of the agreement is startling. He is able to utilize the fact noticed earlier in the acticle, that the masses of the stars are not very different, so that it is easy to take three representative cases—let us say one in which the mass is equal to that on our sun, one in which it is 5 times greater, and one in which it is 5 times less—and by following these three cases in detail he can show the distinctive features of different stars. Briefly, the stepladder is highest for the star of greatest mass, which may get hotter and hotter until it reaches type O; a star of intermediate mass like our sun is arrested at a lower height, and may not reach higher than type F, or at best A, before it begins to fall down the inclined leg; while a star of small mass may reach no higher than type K at any time. The golfers in the audience may be reminded of their handicaps. Those who are destined to be scratch players (probably, however, *not* because of their great mass) improve very rapidly until they reach the highest pitch of excellence, and it may even be only in old age that they begin to travel downwards; but then there are others of long handicap, who although they may improve a

little at first never get beyond the fatal 18 at their best, and on whom declining years soon begin to leave their mark.

One of the most remarkable suggestions of Professor Eddington's work gives a reason for the close resemblance in mass of the stars. There is a certain mass for which the radiation-pressure pressing outwards nearly balances the force of gravitation pulling inwards, and it is clear that for stars as large or larger than this a break-up sooner or later is to be expected. This assigns very obviously the upper limit to the masses—we can easily see why there are no stars larger than a certain limit. But how about the lower limit? Are there no stars *very* much smaller than this? Certainly there are: we are living on one of them. Our earth is smaller by some thousands of times; but then it is not a star in the full sense, for it is not shining with its own light. If it did ever so shine the light must have been feeble at best and have only lasted for a very short time. There may in fact be many small stars, but *we do not see them,* and accordingly have not reckoned them in saying that the masses of the stars are closely similar.[2]

I can not give you a better idea of the value of Professor Eddington's work than by quoting a few words from a letter written to me by Mr. Russell, again specially in response to a request mentioning this lecture: "What appeals to me as the big thing is Eddington's work on radiative equilibrium (MN 77, p. 16 and p. 596). The importance of this can hardly be exaggerated; it is not too much to say that it is the first rational theory of stellar constitution."

Eddington has in fact given us a rough attempt at tracing the history of a star of given mass. By way of illustration let us consider our own sun. He is now a "dwarf star," on the descending leg of the ladder, of spectral type G, and with a surface temperature of about 5,000° C., and an absolute magnitude 5.1. Looking back into the past he was at one time much hotter and of type F, and probably never rose much higher than this on the ladder. Before that his history lay on the ascending leg, and there was a time when his spectral type was just as at present, but his absolute magnitude was near zero, five magnitudes greater than at present. This means that the total light was 100 times greater than now, and since the surface was in a similar radiative state, it must have been 100 times more extensive. The diameter of the sun was therefore ten times the present diameter—ten million miles instead of one million.

[2] On reading this again I realize that it does not do full justice to Eddington's suggestion for the lower limit. He shows a definite difficulty in the formation of small stars.

Where our little earth may have been at that time we can scarcely conjecture, but supposing for a moment that we had been able to regard the sun in our present conditions, he would have taken nearly an hour to rise instead of a few minutes; and when risen, his disc would be ten times as great in all directions—a "giant" sun indeed! And yet this magnification of 10 to 1 is only modest compared with the extreme possibilities.

We set out by the recollection of Jack the Giant Killer, but our road has led us rather to think perhaps of Jack and the Beanstalk. We have climbed up to Giant Land, the land of the giant suns, not by a beanstalk, but by means of the trembling rays of light, a ladder which does not grow upwards from our earth, but is let down to it by the giants themselves. "Fee Fo Fum!" said the Giant, "I smell the blood of an Englishman." In our analogy the giants have been invaded, not by an Englishman, but chiefly by an American; but at any rate we have the satisfaction of reflecting that his work began in Cambridge when he was a student, and that at the end of it there has emanated from Cambridge this brilliant confirmation by Professor Eddington of which the discoverer has himself expressed such generous appreciation.